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Assessment of External Occipital Protuberance Morphometry in CT Scans: Implications for Determining Age and Sex

Evaluación de la Morfometría de la Protuberancia Occipital Externa en Tomografías Computarizadas: Implicaciones para la Determinación de la Edad y el Sexo

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SUMMARY: The study aimed to evaluate the morphological features of the external occipital protuberance (EOP) and skull across different age groups and sexes, focusing on their utility in age and sex determination. Cranial computed tomography images from 1,800 healthy individuals aged 20 to 79 were analyzed. Parameters assessed included EOP height, angle, base diameter, diploic thickness, the distance between the EOP and foramen magnum (FMAG), and the relationship between EOP morphology and cranial shape. The findings revealed that Type II EOP was the most prevalent variant (58 %, n=1,043), while 12 % (n=210) of individuals lacked a prominent EOP. Significant sex-related differences were identified in EOP height, angle, and cranial parameters. A positive correlation was observed between the EOP angle and its distance from the FMAG, particularly in Type III EOP. Multilayer perceptron network analysis highlighted EOP height as a critical factor in sex determination, while regression analysis identified base diameter, FMAG distance, and diploic thickness as significant predictors of both age and sex. This study demonstrated that EOP height, base diameter, FMAG distance, and diploic thickness are valuable parameters for determining age and sex, with potential applications in anthropology and forensic science.

KEY WORDS: External occipital protuberance; Computed tomography; Sex determination; Morphometrical evaluation; Age determination.

INTRODUCTION

The external occipital protuberance (EOP) is a bony projection located on the outer surface of the occipital bone at the level of the superior nuchal line. This anatomical structure serves as an attachment site for the nuchal ligament and neck muscles and exhibits variability in shape due to the mechanical forces acting upon it (Kadri & Al-Mefty, 2007).

The anatomical variant caused by a marked enlargement of the EOP is called an occipital spur, also known as the occipital knob, occipital bun, chignon hook, or inion hook (Srivastava *et al*., 2018; Ibrahim *et al*., 2023). The occipital spur may present symptomatically in some patients, causing pain and a palpable, tense bony prominence at the back of the head and neck. In other cases, it may remain asymptomatic and be identified incidentally during radiological evaluations. Surgical excision may be required for cases associated with persistent pain (Marshall *et al*., 2015). On the other hand, this formation may rarely be fractured due to trauma (Sattur *et al*., 2019).

The EOP is an important target area for nerve block (Güvençer *et al*., 2011; Moriggl & Greher, 2018), occipitocervical fusion (Ebraheim *et al*., 1996; Zipnick *et al*., 1996; Zarghooni *et al*., 2016), and sex determination (Kim & Han, 2015; Gülekon & Turgut, 2003) and has been investigated by different methods such as direct radiography (Gülekon & Turgut, 2003), ultrasonography (Moriggl & Greher, 2018), computerized tomography (Batista *et al*., 2015), and magnetic resonance imaging (Tsutsumi *et al*., 2022).

There are three types of EOP depending on their shape (Gülekon & Turgut, 2003; Marshall *et al*., 2015; Ibrahim *et al*., 2023): “flat or smooth type” (Type I), “crest type” (Type II), and “spine type” (Type III). Previous studies have shown

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that Type 1 was more frequent in women and type 3 in men (Gülekon & Turgut, 2003; Shahar & Sayers, 2016). Type 3 can sometimes manifest as a subcutaneous scalp pseudotumor (Gómez Zubiaur *et al*., 2019).

Computed Tomography (CT) is more effective than conventional radiography in detecting subtle bone changes. This increased precision may account for the apparent overestimation of the prevalence and size of the external occipital protuberance (EOP) compared to radiographic or morphological analyses. Notably, our results are consistent with a previous study using conventional radiographs (Shahar & Sayers, 2016), which reported an enlarged EOP in 41 % of individuals, compared to 44.2–44.9 % observed in our study, with a higher prevalence in men (67.4 %) compared to women (20.3 %) (Zarghooni *et al*., 2016). Conversely, a morphological study of cadaveric skulls reported a prevalence of only 10 % (Srivastava *et al*., 2018). Additionally, it has been observed that men tend to have increased occipital bone thickness in the region surrounding the EOP. As a result, imaging techniques may overestimate the prevalence of EOP enlargement compared to morphological studies, potentially due to the difficulty in differentiating the deep portion of the EOP from localized thickening of the occipital bone.

This study investigated the relationships between the type, height, base, and angle of the EOP and its distance from the foramen magnum. Additionally, morphometric findings were compared across head shape variations and sexes. Finally, the study aimed to evaluate the potential role of the collected data in sex determination.

MATERIAL AND METHOD

This study is a retrospective, cross-sectional descriptive study, and the morphological data obtained were used to determine sex and age using artificial neural networks and statistical tools.

Ethical approval. The non-interventional clinical research ethics committee of the medical faculty approved the study protocol (Approval number: 2024.109.05.17, Date: 28.05.2024). All patients reviewed and signed the informed consent form. The people participating in the study were treated in accordance with the 1964 Declaration of Helsinki and its amendments.

Study population. Between January 2023 and March 2024, a total of 1800 patients (909 males, 891 females) aged 20-79 years who underwent cranial CT examination in the radiology department of a university hospital were included in the study.

Inclusion and exclusion criteria. Patients with optimal image quality and EOP detected on CT examination were included in the study. Conditions affecting bone morphology and integrity (such as surgery, trauma, lesions, etc.) and patients without optimal CT image quality were excluded.

Non-enhanced CT scanning protocol. The cranium was scanned from the level of the vertex to the level of the skull base and images were obtained in the axial plane. Then, sagittal and coronal images were reformatted. CT scan parameters are as follows: tube voltage 120 kVp, tube current 220 mAs, rotation time 0.75 seconds, section thickness 1 mm, FOV 220 mm, and slice interval 0.8 mm.

Imaging assessment and measurements. A radiologist with 12 years experience measured and evaluated the images. All examinations were performed in the bone window (Window:1500, Level:450).

Morphometric parameters such as EOP prevalence, EOP types (Type I, Type II, and Type III) (Fig. 1), the diameter of the EOP base, height, angle; diploe distance, and the distance of the EOP to the foramen magnum (Fig. 2) were recorded on the Sectra 7.0 workstation. Patients with no types were categorized as NONE (the thickness of the external lamina was less than 4.5 mm). All measurements of EOP were performed on the sagittal plane.

Fig. 1. The external occipital protuberance and its types on sagittal CT images. (a) and (b) normal patients (b, external lamina thickness <4.5 mm); (c) Type I EOP; (d) Type II EOP, and (e) Type III.

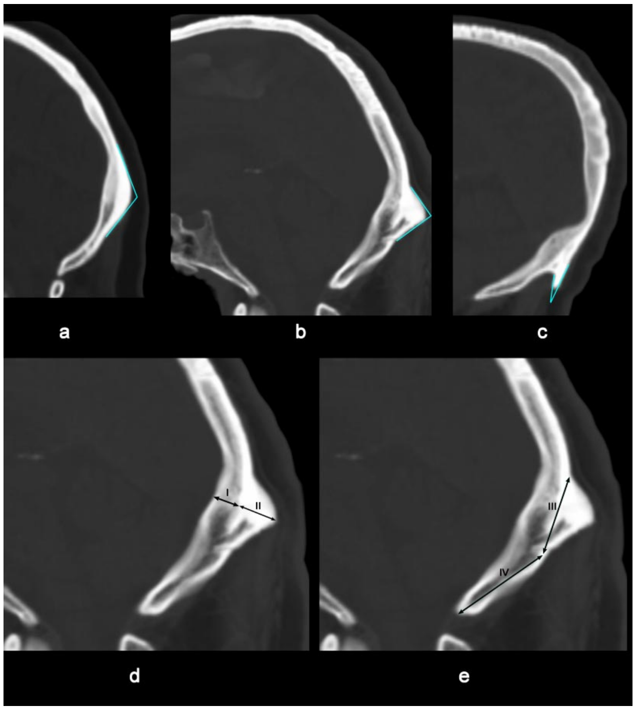

Fig. 2. EOP measurements. (a-c) angle measurements in EOP types; (d) diploe distance (I) and EOP height (II); (e) EOP base width (III) and distance of EOP to foramen magnum (IV).

EOP ratios (including height/base, height/diploe distance, and height/angle ratios) and EOP measurement parameters according to age groups were evaluated. The relationship of EOP with sex dimorphism and cranial shape (Fig. 3) was statistically analyzed.

Statistical analysis. Statistical package program (SPSS Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc) was used. After the normality tests (Shapiro-Wilk / Kolmogorov-Smirnov) were performed, non-parametric tests were applied since the data did not show normal distribution. Descriptive tests were used for demographic data (age, sex, etc.). Mann-Whitney U test was used for pairwise comparison of groups and Kruskal Wallis test was used for comparison of more than two groups. The chi-square test was used in the evaluation of categorical data and the Spearman Rho test was used in correlation analysis. Data were categorized according to age groups. The statistical significance level was accepted as $p<0.05$.

Sex and age group estimation using artificial neural network. The multilayer perceptron network analysis in SPSS used the measured parameters for sex and age determination. Training and testing results and the parameters independent variable importance levels in the model were determined.

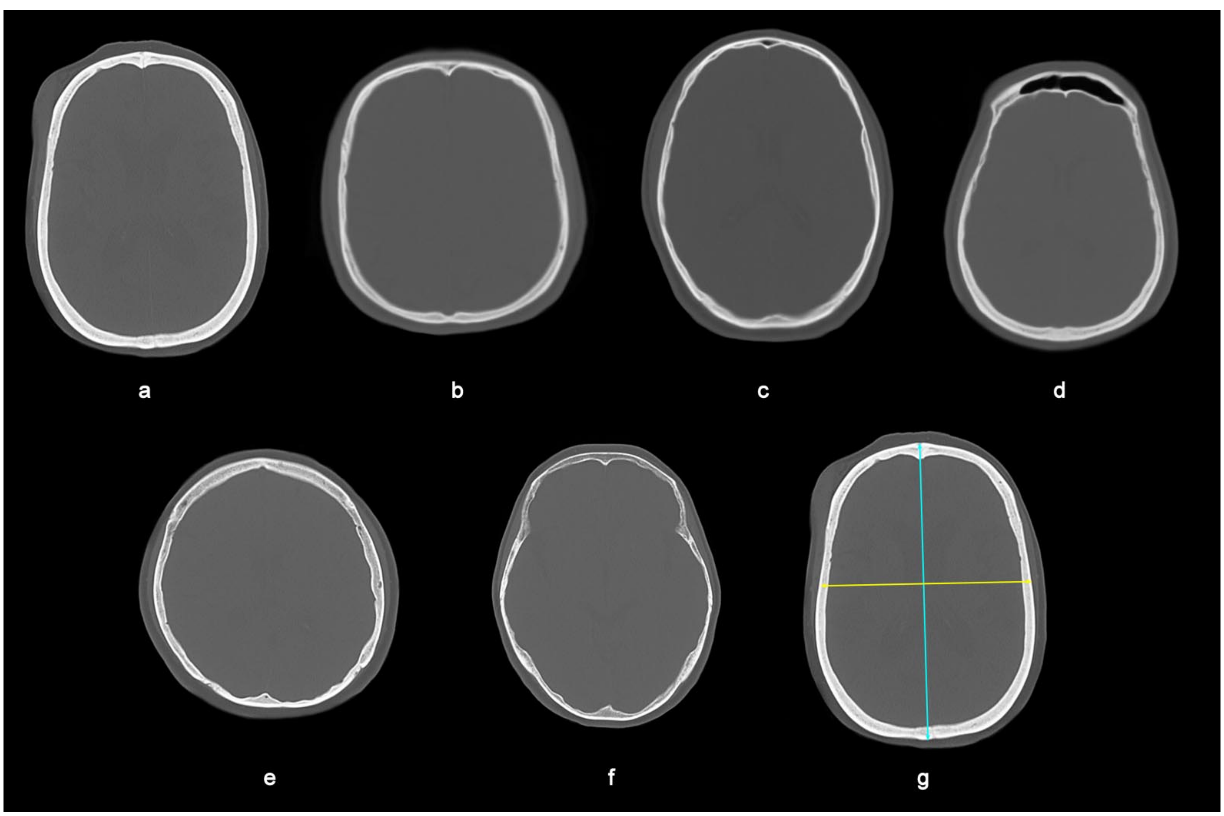

Fig. 3. Cranial shapes. (a) rectangular; (b) square; (c) ellipse; (d) oval (egg-shaped); (e) round; (f) fusiform; (g) anteroposterior (AP) diameter (blue arrow) and transverse (TR) diameter (yellow arrow) of the cranium. Cephalic index=TR/AP*100.

RESULTS

In our study, CT images of 1800 individuals (891 females, 909 males) aged 20-79 years were included and the values of 1590 individuals with prominent EOP were analyzed separately. In the study, morphological values were compared in 6 age groups including 300 individuals in deciles.

The mean and standard deviation values of the measured parameters related to EOP and cranium in the cases included in the study are given in (Table I). In cases without significant EOP observed, EOP-related parameters could not be measured and are shown as "Not Applicable".

In our study, the frequency of EOP types according to age groups in six deciles (20-29, 30-39, 40-49, 50-59, 60-69, and 70-79) was investigated and compared statistically. In the 20-29 age group, Type I was seen in 74 cases, Type II in 149 cases, and Type III in 30 cases, while EOP could not be differentiated in 47 cases. In the 30-39 age group, Type I was seen in 54 cases, Type II in 175 cases, and Type 3 in 27 cases, while EOP could not be differentiated in 44 cases. In the 40-49 age group, Type I was seen in 50 cases, Type II in 188 cases, and Type III in 22 cases, while EOP could not be differentiated in 35 cases. In the 50-59 age group, Type I was seen in 50 cases, Type II in 189 cases, and Type III in 30 cases, while EOP could not be differentiated in 26 cases. In the 60-69 age group, Type I was seen in 80 cases, Type II in 176 cases, and Type III in 28 cases, while EOP could not be differentiated in 16 cases. In the 70-79 age group, Type I was seen in 86 cases, Type II in 166 cases, and Type 3 in 20 cases, while EOP could not be differentiated in 28 cases. According to the Chi-square test results, a significant difference was found between age groups ($p<0,001$).

Height, base, distance to the FMAG, angle of the EOP, AP, and transverse lengths of the cranium were compared between the EOP types, and significant differences were observed in all other comparisons ($p<0.001$) except for the distance to the FMAG of Type II and Type III EOPs ($p=0.199$).

The correlation analysis was another analysis we performed on the data we obtained. Accordingly, the correlations of the morphometric characteristics of the EOPs, which we classified as 3 types, were analyzed and summarised in **(**Table II)**.**

Table I. Descriptive statistics of the total cases.

	NONE (n=210)	TYPE I (n=394)	TYPE II (n=1043)	TYPE III (n=153)	TOTAL(n=1590)
AGE (years)	44.50 ± 17.11	50.72 ± 18.45	49.43 ± 16.78	47.64 ± 17.33	49.58 ± 17.28
HEIGHT (mm)	N/A	5.54 ± 1.10	8.40 ± 2.38	10.08 ± 3.32	7.85 ± 2.66
BASE (mm)	N/A	31.19 ± 8.20	26.89 ± 7.85	23.15 ± 8.47	27.60 ± 8.33
FMAG Distance (mm)	N/A	32.40 ± 6.87	33.41 ± 6.48	33.95 ± 6.47	33.21 ± 6.59
DIPLOE (mm)	10.26 ± 2.64	7.83 ± 1.91	7.73 ± 1.85	7.73 ± 1.91	7.76 ± 1.87
ANGLE (degree)	N/A	134.33 ± 11.76	114.68 ± 21.28	32.73 ± 17.44	111.67 ± 33.07
CR_AP (mm)	167.79 ± 8.70	168.14 ± 8.47	171.62 ± 8.98	173.292 ± 9.26	170.92 ± 9.03
CR_TR (mm)	138.75 ± 5.93	139.89 ± 6.68	141.98 ± 6.86	142.61 ± 6.52	141.52 ± 6.85
AP_TR RATE	1.21 ± 0.07	1.20 ± 0.07	1.21 ± 0.07	1.22 ± 0.08	1.21 ± 0.07
Cephalic Index	82.87 ± 4.73	83.35 ± 4.94	82.89 ± 4.94	82.49 ± 5.26	82.97 ± 4.97

HEIGHT, height of EOP; BASE, base of EOP; FMAG Distance, distance of EOP to foramen magnum; DIPLOE, thickness of diploe at the EOP; ANGLE, angle of the Type III EOP; CR_AP, anteroposterior length of the cranium; CR_TR, transverse length of the cranium; AP_TR_RATE, rate of the anteroposterior to transverse diameters of the cranium.

Table II. Correlation coefficients of morphological features classified by EOP types.

	NONE (n=210)	TYPE I (n=394)	TYPE II (n=1043)	TYPE III (n=153)	TOTAL(n=1590)
AGE (years)	44.50 ± 17.11	50.72 ± 18.45	49.43 ± 16.78	47.64 ± 17.33	49.58 ± 17.28
HEIGHT (mm)	N/A	5.54 ± 1.10	8.40 ± 2.38	10.08 ± 3.32	7.85 ± 2.66
BASE (mm)	N/A	31.19 ± 8.20	26.89 ± 7.85	23.15 ± 8.47	27.60 ± 8.33
FMAG Distance (mm)	N/A	32.40 ± 6.87	33.41 ± 6.48	33.95 ± 6.47	33.21 ± 6.59
DIPLOE (mm)	10.26 ± 2.64	7.83 ± 1.91	7.73 ± 1.85	7.73 ± 1.91	7.76 ± 1.87
ANGLE (degree)	N/A	134.33 ± 11.76	114.68 ± 21.28	32.73 ± 17.44	111.67 ± 33.07
CR_AP (mm)	167.79 ± 8.70	168.14 ± 8.47	171.62 ± 8.98	173.292 ± 9.26	170.92 ± 9.03
CR_TR (mm)	138.75 ± 5.93	139.89 ± 6.68	141.98 ± 6.86	142.61 ± 6.52	141.52 ± 6.85
AP_TR RATE	1.21 ± 0.07	1.20 ± 0.07	1.21 ± 0.07	1.22 ± 0.08	1.21 ± 0.07
Cephalic Index	82.87 ± 4.73	83.35 ± 4.94	82.89 ± 4.94	82.49 ± 5.26	82.97 ± 4.97

Correlation is significant at the 0.01 level (2-tailed). Correlation is significant at the 0.05 level (2-tailed). HEIGHT, height of EOP; BASE, base of EOP; FMAG Distance, distance of EOP to foramen magnum; DIPLOE, thickness of diploe at the EOP; ANGLE, angle of the Type III EOP; CR_AP, anteroposterior length of the cranium; CR_TR, transverse length of the cranium; AP_TR_RATE, rate of the anteroposterior to transverse diameters of the cranium.

Table III. Mean and standard deviation values and statistical comparison results of the parameters analysed on sex basis.

	Male (n=877)	Female (n=713)	p-value
AGE (years)	48.75 ± 17.41	50.60 ± 17.07	0.285
HEIGHT (mm)	8.98 ± 2.74	6.46 ± 1.74	<0.001
BASE (mm)	27.37 ± 8.10	27.89 ± 8.59	0.139
FMAG Distance (mm)	33.38 ± 6.50	33.00 ± 6.70	0.564
DIPLOE (mm)	7.68 ± 1.82	7.85 ± 1.94	0.249
ANGLE (degree)	104.33 ± 33.70	120.69 ± 29.92	<0.001
CR_AP (mm)	173.75 ± 8.81	167.44 ± 8.05	<0.001
CR_TR (mm)	143.50 ± 6.78	139.09 ± 6.11	<0.001
AP_TR RATE	1.21 ± 0.08	1.21 ± 0.07	0.06
Cephalic Index	82.77 ± 5.22	83.22 ± 4.64	0.05

HEIGHT, height of EOP; BASE, base of EOP; FMAG Distance, distance of EOP to foramen magnum; DIPLOE, thickness of diploe at the EOP; ANGLE, angle of the Type III EOP; CR_AP, anteroposterior length of the cranium; CR_TR, transverse length of the cranium; AP_TR_RATE, rate of the anteroposterior to transverse diameters of the cranium.

Table IV. Distribution of the classification of head types according to cephalic index according to sex.

Skull Type	Male (n, %)	Female (n, %)	Total (n, %)
Dolicocephaly (65.0 - 74.9)	49 (5.6)	23 (3.2)	72
Mesocephaly (75.0 - 79.9)	233 (26.6)	153 (21.5)	386
Brachicephaly (80.0 - 84.9)	298 (34.0)	289 (40.5)	587
Hyperbrachicephaly (85.0 - 89.9)	219 (25.0)	193 (27.1)	412
Ultrabrachicephaly (>90.0)	78 (8.9)	55 (7.7)	133
TOTAL	**877**	**713**	**1590**

Table V. Comparison results of measured parameters between groupings according to cephalic index.

	Skull Type	n	Mean Rank	Kruskal Wallis Test (p value)
Height	Dolicocephaly (65.0 - 74.9)	72	823.57	0.067
	Mesocephaly (75.0 - 79.9)	386	838.01	
	Brachycephaly (80.0 - 84.9)	587	772.57	
	Hyperbrachicephaly (85.0 - 89.9)	412	763.11	
	Ultrabrachicephaly (>90.0)	131	847.31	
Base	Dolicocephaly (65.0 - 74.9)	72	734.88	**0.010**
	Mesocephaly (75.0 - 79.9)	386	766.06	
	Brachycephaly (80.0 - 84.9)	587	767.29	
	Hyperbrachicephaly (85.0 - 89.9)	412	851.61	
	Ultrabrachicephaly (>90.0)	131	853.39	
FMAG_distance	Dolicocephaly (65.0 - 74.9)	72	917.65	**0.000**
	Mesocephaly (75.0 - 79.9)	386	860.09	
	Brachycephaly (80.0 - 84.9)	587	828.27	
	Hyperbrachicephaly (85.0 - 89.9)	412	704.77	
	Ultrabrachicephaly (>90.0)	131	664.40	
Diploe	Dolicocephaly (65.0 - 74.9)	72	834.53	**0.000**
	Mesocephaly (75.0 - 79.9)	386	875.06	
	Brachycephaly (80.0 - 84.9)	587	802.60	
	Hyperbrachicephaly (85.0 - 89.9)	412	745.34	
	Ultrabrachicephaly (>90.0)	131	653.48	
Angle	Dolicocephaly (65.0 - 74.9)	72	666.84	**0.001**
	Mesocephaly (75.0 - 79.9)	386	745.73	
	Brachycephaly (80.0 - 84.9)	587	795.44	
	Hyperbrachicephaly (85.0 - 89.9)	412	858.41	
	Ultrabrachicephaly (>90.0)	131	803.16	

Sex-based comparison of EOP and cranium-related parameters measured and independent T-test results are given in (Table III). The correlation between the measured parameters was analyzed separately in males and females. A strong negative correlation was observed between angle and height in both sexes (male -0.514 and female -0.307, $p<0.01$). In contrast, a positive correlation was observed between EOP height and cranium AP and TR lengths in males (0.096 and 0.077, respectively). A strong negative correlation was observed between EOP angle and CR-AP (-0.098).

The frequency of head types according to sex and comparison results are given in (Table IV). The comparison results of the measured parameters according to the head types are given in (Table V). All parameters except EOP height differed between head types.

The results of sex determination by multilayer perceptron network analysis are shown in (Table VI). When EOP and cranial parameters were used for predicting sex by artificial neural network analysis, the prediction rate of female cranium was higher.

The importance of the parameters used in sex determination with artificial neural network analysis is given in (Fig. 4). In determining age groups by multilayer perceptron network analysis, testing results showed different distributions due to more groups compared to sex. On the other hand, the graph of specificity/ sensitivity is given in (Fig. 5) and it is found to be quite high for each group.

Independent variable importance analysis results for age group prediction are given in (Fig. 6). The results of the estimation of sex and age groups by stepwise regression analysis are given in (Tables VII and VIII), respectively.

Table VI. Sex determination by multilayer perceptron network analysis.

Classification				
		Predicted		
Sample	Observed	Male	Female	Percent Correct
Training	Male	427	206	67.5 %
	Female	131	505	79.4 %
	Overall Percent	44.0 %	56.0 %	73.4 %
Testing	Male	24	8	75.0 %
	Female	6	25	80.6 %
	Overall Percent	47.6 %	52.4 %	77.8 %

Dependent Variable: Sex

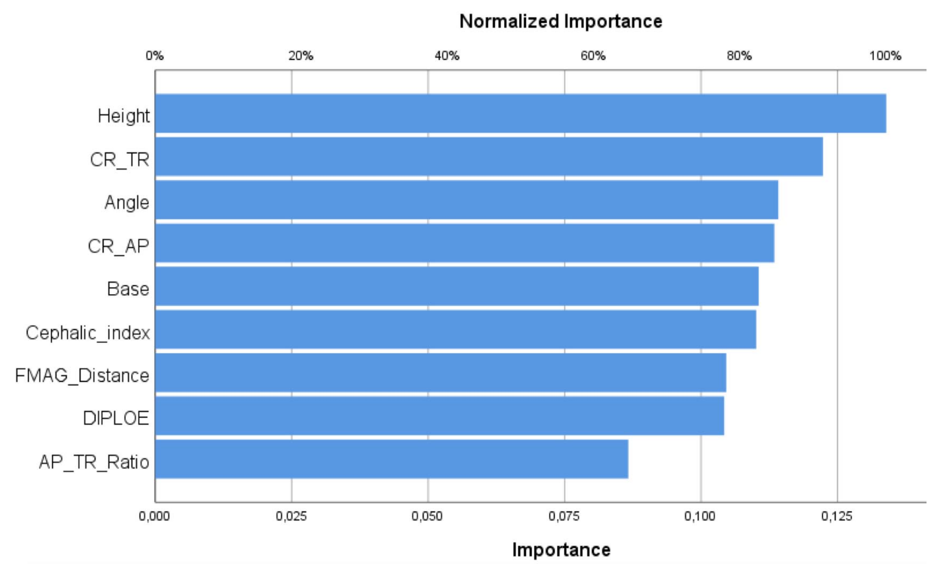

Fig. 4. Importance of ranking the parameters used in sex determination with artificial neural network analysis.

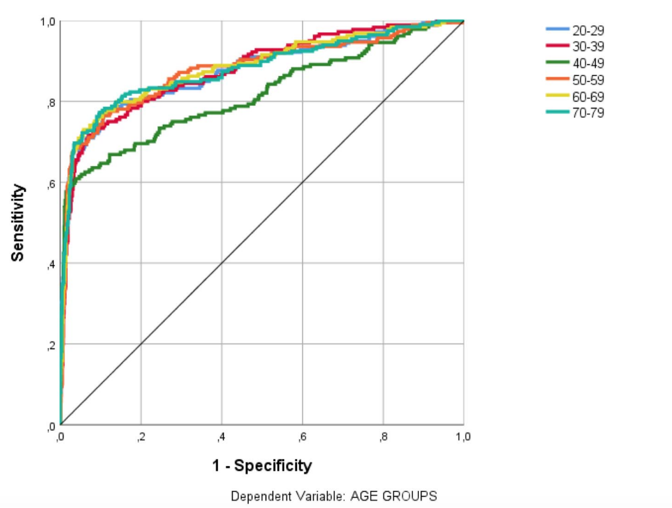

Fig. 5. Specificity and sensitivity graphic for age determination.

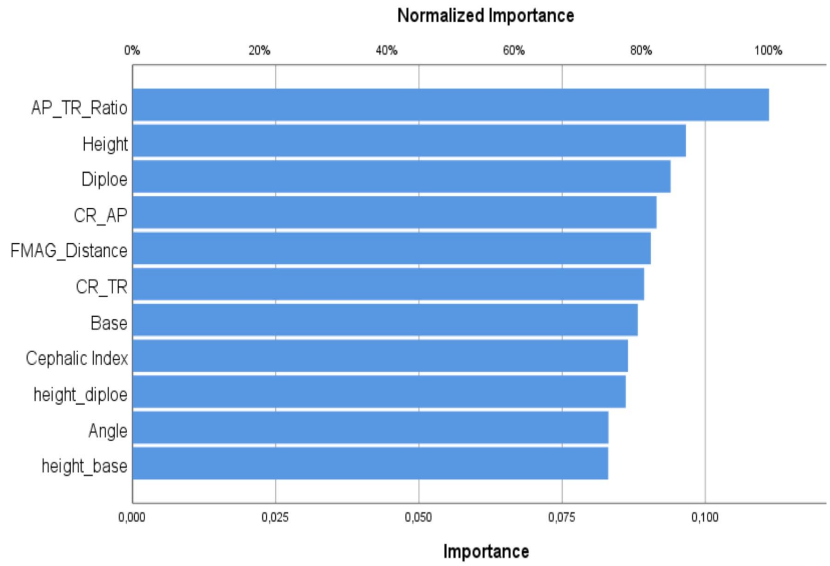

Fig. 6. Independent variable importance analysis results for age group prediction.

Table VII. Results of the sex prediction by stepwise regression analysis.

Sex	Predictors	B	SE	β	t	p	R^2	Adj. R^2
Model 1	Height	-0.089	0.004	-0.473	-21.424	<0.001	0.224	0.223
Model 2	Height	-0.093	0.004	-0.495	-22.220	<0.001	0.237	0.236
	Base	0.007	0.001	0.120	5.337	<0.001		
Model 3	Height	-0.094	0.004	-0.500	-22.404	<0.001	0.241	0.239
	Base	0.006	0.001	0.098	4.088	<0.001		
	FMAG distance	-0.005	0.002	-0.063	-2.651	0.008		
Model 4	Height	-0.094	0.004	-0.501	-22.512	<0.001	0.244	0.242
	Base	0.005	0.001	0.091	3.767	<0.001		
	FMAG distance	-0.005	0.002	-0.069	-2.879	0.004		
	Diploe	0.016	0.006	0.059	2.658	0.008		

Notes. SE = Std. Error; Model 1: (F=459.01, p<0.001); Model 2: (F=247.70, p<0.001); Model 3: (F=168.10, p<0.001); Model 4: (F=128.325, p<0.001). HEIGHT, height of EOP; BASE, base of EOP; FMAG Distance, distance of EOP to foramen magnum.

Table VIII. Results of the age group prediction by stepwise regression analysis.

Sex	Predictors	B	SE	β	t	p	R^2	Adj. R^2
Model 1	CR_AP	-0.054	0.005	-0.286	-11.876	<0.001	0.082	0.081
Model 2	CR_AP	-0.052	0.004	-0.274	-11.707	<0.001	0.131	0.130
	Base	0.046	0.005	0.223	9.536	<0.001		
Model 3	CR_AP	-0.057	0.005	-0.301	-12.456	<0.001	0.141	0.139
	Base	0.042	0.005	0.203	8.554	<0.001		
	Height	0.066	0.016	-0.103	4.193	<0.001		

Notes. SE = Std. Error; Model 1: (F=141.03, p<0.001); Model 2: (F=119.98, p<0.001); Model 3: (F=86.68, p<0.001). HEIGHT, height of EOP; BASE, base of EOP; CR_AP, anteroposterior length of the cranium

DISCUSSION

This study not only reported the occurrence of EOP variation and morphometric properties but also identified factors that can be utilized for age and sex estimate. It accomplished this by highlighting the disparities in the morphological characteristics of EOP between different sexes and age groups. This work presents, for the first time in the existing body of literature, the measured characteristics (angle, height, and base width) of EOP.

Recent studies indicate a significant rise in the occurrence of enlargement of the EOP (external occipital protuberance) in young people (Shahar & Sayers, 2016, 2019). These studies suggest that mechanical variables, such as the forward protraction of the head, contribute to this increase and subsequently lead to musculoskeletal issues in this particular group (Shahar & Sayers, 2019). The concept of a potential correlation with smartphone usage has been proposed, but no definitive connection has been established thus far, primarily due to a significant number of confounding variables. However, if there is a genuine increase in the occurrence and size of larger EOP in young people, it would indicate a substantial evolutionary push occurring within a relatively little period. Furthermore, the aforementioned findings (Shahar & Sayers, 2016, 2019) relied on the analysis of direct graphy exams, which is an unsatisfactory technique for evaluating a three-dimensional structure. Furthermore, it was underscored that the longitudinal assessment conducted in this research was inadequate. Our study demonstrated the enlargement of the EOP can also be observed in older individuals, as evidenced by examinations conducted on individuals aged 20-79 years. Conversely, variations in angles were noted among different age groups.

The EOP is a bony structure on the occipital bone with various clinical and anthropological implications. It can be used for sex determination in forensic contexts, with Type III (spine-like) EOP being more common in males and Type I (less prominent) in females (Gülekon & Turgut, 2003). In our study, no significant difference was observed between males and females in terms of Type III (7.4 % and 11.4 %, respectively), whereas Type I was observed 4 times more in females compared to males (42.4 % and 10.5 %, respectively), similar to previous studies.

Enlarged EOPs or osteophytes may cause occipital headaches, particularly in athletes performing vertical neck movements (Singh, 2012). Recent studies suggest that excessive screen use and prolonged postures may contribute to structural changes in the EOP, which can be assessed using ultrasound (Benito Domingo & García Godino, 2020). Conversely, there was no relationship between smartphone use and EOP in the studies conducted (Jacques *et al*., 2020; Porrino *et al*., 2021). In our study, no correlation was observed between EOP parameters and individuals in different deciles; therefore, there was no evidence of a relationship between increased mobile phone use by young people and EOP types.

In a study including a sample of 1000 patients aged 25-50 years, selected randomly, consisting of 500 women and 500 men, it was found that males were five times more prone to displaying the Type III form of EOP compared to females, as observed using lateral head graphics. 63.4 % of males exhibited Type III, while Type I was seen in 17.8 % of males. In contrast, Type I was identified in 85.4 % of females, while Type III was found in just 4.2 % of females. The prevalence of Type II EOP was similar in both males and females. A significant statistical difference was seen between sex and EOP types (Gülekon & Turgut, 2003). The present study found that the occurrence of EOP was 80 % in males and 97 % in females. Furthermore, there are 1800 patients in total (909 men and 891 women) who are spread throughout a wide age range of 20 to 79 years in this study.

The muscle mass/body weight ratio is less in females than in males might be the reason why the EOP is more prominent in males following the power of neck muscles (Gülekon & Turgut, 2003). In another study, the mean length of Type III EOP was measured as 16.63 mm, mean width as 20.1 mm and mean thickness as 7.82 mm in dry skulls. In our study, the length of Type III EOP was 10.08 mm, and the base width was 23.15 mm in CT images of healthy subjects. We think that the reason for the difference in length may be due to age, postmortem changes or measurement methods.

In the study by Jacques *et al*. (2020), the volumetric analysis of EOP Type III was done in two populations of young adults (2011 and 2019) the result showed an increasing

Table IX. Literature review of EOP studies.

	Jacques *et al*. (2011)	Jacques *et al*. (2019)	Caglayan *et al*. (2024)	Our Study
All participants	N=205	N=240	N=523	N=1800
Type I	55.1 % (n=113)	55.8 % (n=134)	23.1 % (n=121)	21.9 % (n=394)
Type II	31.2 % (n=64)	29.6 % (n=71)	15.3 % (n=80)	57.9 % (n=1043)
Type III	13.7 % (n=28)	14.6 % (n=35)	7.2 % (n=38)	8.5 % (n=153)
Female	N=87	N=106	N=314	N=891
Type I	82.8 % (n=72)	83.0 % (n=88)	18.5 % (n=58)	33.9 % (n=302)
Type II	10.3 % (n=9)	10.4 % (n=11)	13.4 % (n=42)	40.2 % (n=358)
Type III	6.9 % (n=6)	6.6 % (n=7)	4.1 % (n=13)	5.9 % (n=53)
Male	N=118	N=134	N=209	N=909
Type I	34.7 % (n=41)	34.3 % (n=46)	39.7 % (n=83)	10.1 % (n=92)
Type II	46.6 % (n=55)	44.8 % (n=60)	18.2 % (n=38)	75.4 % (n=685)
Type III	18.7 % (n=22)	20.9 % (n=28)	12.0 % (n=25)	11.0 % (n=100)

rate of EOP over time in both sexes predominantly in males (Table IX). We conducted a study where we studied the cranium of a significantly larger number of individuals, and we noticed the sample size of people analyzed in prior studies. We propose that our study, which included a larger number of patients, yielded more reliable findings.

Over the past decade, the utilization of mobile phones has shown a three to fivefold growth across various age demographics, with a rise ranging from 86 % to 95 % among individuals aged 12 to 40 (Shahar & Sayers, 2016; Srivastava *et al*., 2018; Shahar & Sayers, 2019). Mobile phone usage is believed to lead to postural alterations in individuals, particularly forward flexion of the head, which is likely to increase the strain on the neck and the workload of the muscles in this region. The augmentation of muscle contraction leads to the remodelling of bone structures, resulting in their increased prominence. Research investigating the correlation between mobile phone usage and expansion of the EOP has yielded conflicting findings. There is a suggestion that variables resulting from variations among individuals could be useful in addressing this problem, and that this challenge can be handled using various approaches. Our investigation utilized particular characteristics, including the angle of the external occipital protuberance (EOP) and the correlation between diploe and height. However, due to the lack of recorded phone usage data for the subjects, it was not possible to make a comparison in order to address this point. Conversely, the similarity in characteristics between older age groups, who are presumed to use smartphones less frequently, and younger groups undermines the correlation between phone usage and EOP structure.

In another study conducted in the age group of 30 years and younger, contrary to our findings, Type II EOP was observed less frequently (Çaglayan *et al*., 2024).

Several studies have investigated the occipital bone for sex determination in forensic and bioarchaeological contexts. The occipital condyles have been a focus of research, with studies examining their shape, antero-posterior diameter, transverse diameter, and occipital condyle index (Sholapurkar *et al*., 2017). The foramen magnum and occipital condyle dimensions have also been analyzed using computed tomography, showing significant differences between males and females (Rai *et al*., 2017). Additionally, the basal region of the occipital bone has been studied using classical osteometric methods, although with limited success in a French sample (Macaluso Jr., 2011). Research has also explored the condylar region of the occipital bone, considering the effects of age and ancestry on sexual dimorphism (Wescott & Moore-Jansen, 2001). In our study, the role of EOP in sex and age determination was investigated and it was found to be effective in predicting eighty percent, with a higher success rate in women. While some studies have reported high accuracy in sex determination using occipital bone measurements (Rai *et al*., 2017), others have found limited success (Wescott & Moore-Jansen, 2001; Macaluso Jr., 2011), highlighting the need for population-specific approaches.

Pedigree studies show that nuchal anatomical features have little or no heritability (Vark & Howells, 1984). This is also valid for EOP and emphasizes the effect of environmental and biomechanical characteristics. However, in our study, EOP differed between sexes, and it was thought to differ in relation to other characteristics of the two sexes.

Strengths and Limitations. Our study has a powerful side in terms of reflecting the population as it has a large sample set consisting of 1800 people. In addition, age grouping, which consists of an equal number of six deciles, constitutes a great advantage in terms of analyzing age-related changes in adult individuals. In our study, the first known information about the angle and distance to the foramen magnum related to the EOP is included.

In conclusion, the results of this study are of great importance for forensic medicine and archaeological research, as well as guiding radiological and interventional procedures. For example, it will be a useful guide for determining the age range and sex of a skull of unknown age.

Ethical approval. The study was designed as a retrospective study which has been approved by the local ethical committee of Tekirdag Namık Kemal University, Faculty of Medicine, Tekirdag, Turkey (Approval number: 2024.109.05.17, Date: 28.05.2024).

SASANI, H.; OZKAN, M. & CELIK, H.H. Evaluación de la morfometría de la protuberancia occipital externa en tomografías computarizadas: Implicaciones para la determinación de la edad y el sexo. *Int. J. Morphol., 43(3)*:1011-1020, 2025.

RESUMEN: El estudio tuvo como objetivo evaluar las características morfológicas de la protuberancia occipital externa (POE) y el cráneo en individuos de diferentes grupos de edad y sexo, centrándose en su utilidad para la determinación de la edad y el sexo. Se analizaron imágenes de tomografía computarizada craneal de 1800 individuos sanos de entre 20 y 79 años. Los parámetros evaluados incluyeron la altura, el ángulo, el diámetro de la base, el grosor diploico de la POE, la distancia entre la POE y el foramen magnum (FMAG) y la relación entre la morfología de la POE y la forma del cráneo. Los hallazgos revelaron que el EOP Tipo II fue la variante más prevalente (58 %, n = 1043), mientras que el 12 % (n = 210) de los individuos carecía de un EOP prominente. Se identificaron diferencias significativas relacionadas con el sexo en la altura, el ángulo y los parámetros craneales del EOP. Se observó una correlación positiva entre el ángulo del EOP y su distancia al FMAG, particularmente en el EOP Tipo III. El análisis de red perceptrónica multicapa destacó la altura del EOP como un factor crítico en la determinación del sexo, mientras que el análisis de regresión identificó el diámetro de la base, la distancia al FMAG y el grosor diploico como predictores significativos tanto de la edad como del sexo. Este estudio demostró que la altura, el diámetro de la base, la distancia al FMAG y el grosor diploico del EOP son parámetros valiosos para determinar la edad y el sexo, con posibles aplicaciones en antropología y ciencias forenses.

PALABRAS CLAVE: Protuberancia occipital externa; Tomografía computarizada; Determinación del sexo; Evaluación morfométrica; Determinación de la edad.

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